

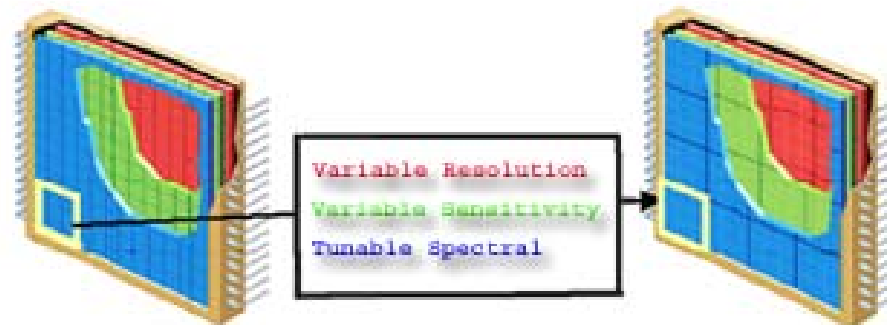
Joint Design of Optics and Array Processing

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Joint Optimization

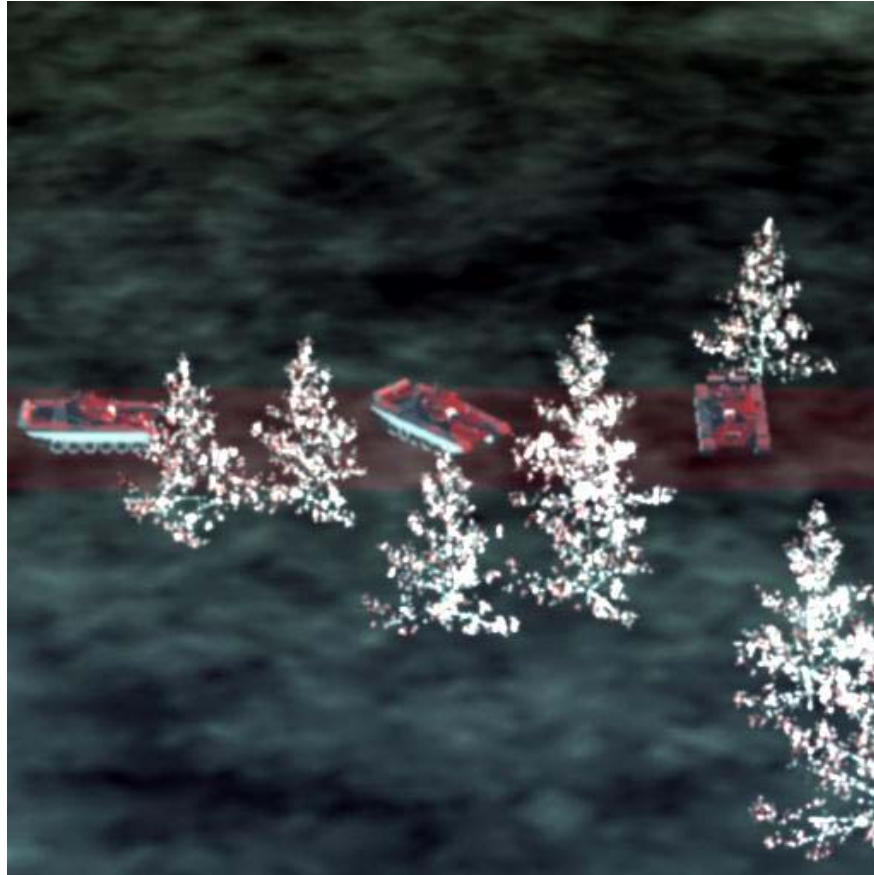


Feature Based Tracking

ATR:

Target Chip Registration

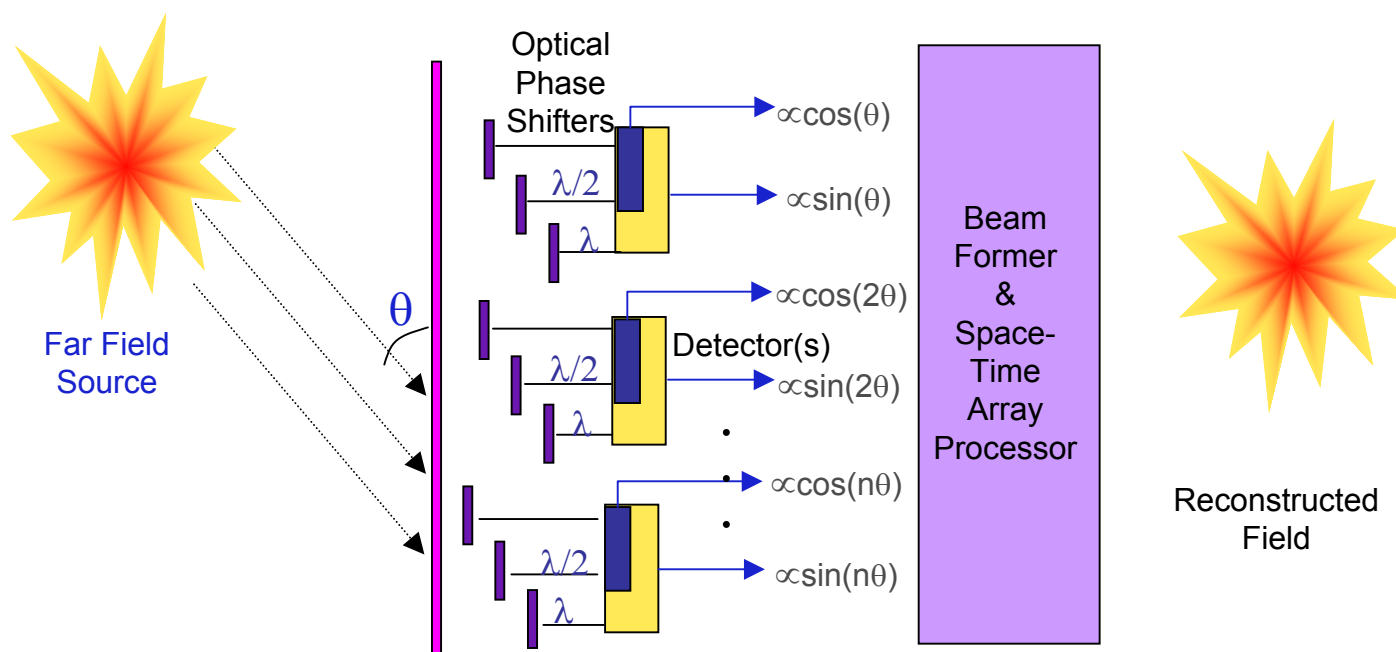
Signature Variation



Phase Representation for Optics Design

- **Radar Analogue (Manipulations of Sensed Field)**
 - **Optics Reduced to Thin Aperture**
 - **Sensed Field Reconstructed with Adaptive Array Processing - RADAR ANALOG**
 - **Control Optical Patterns, Null and Enhance Desired Image Features with Beamforming Techniques**
 - **Non-linear Phase Manipulation for Novel and Enhanced Imaging**
 - **Variable Resolution, Resolution Controlled on Physical Layer by Beam Forming, Extendable to Passive Optical Synthetic Arrays**
 - **Highly Challenging Processing Throughput**

What is an Optical Array



Subject to temporal and spatial
coherence constraints of course

APPLICATION CONCEPTS

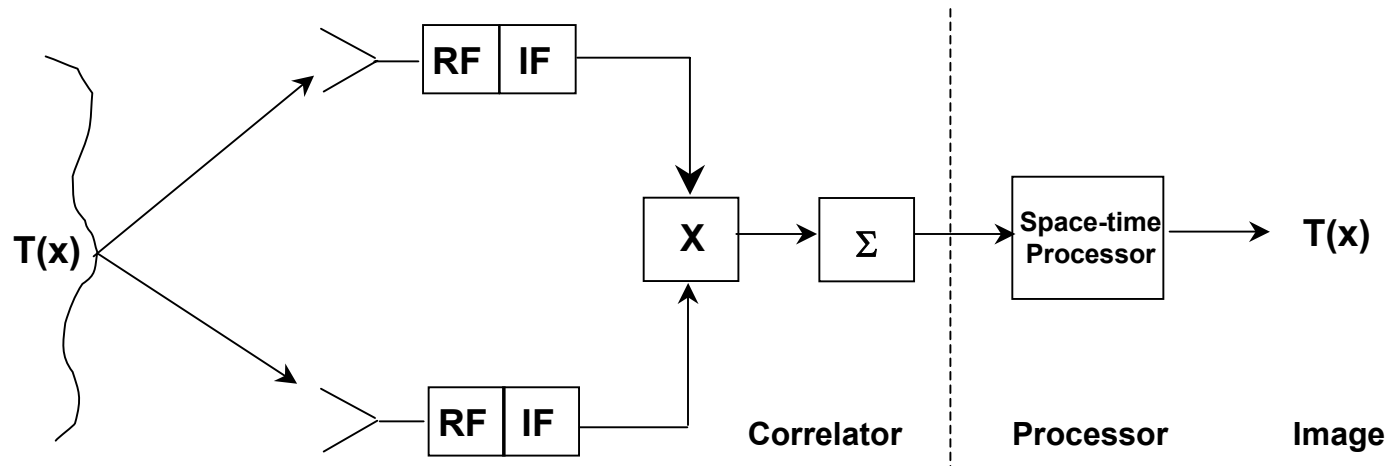
Optical Reconnaissance and
Photo-Optical Development
are required to use this product.

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360 Conformal
Optical Ball

Conformal
Optical Hemisphere

Synthetic Aperture Radiometer



- **Objective of Aperture Synthesis is to Obtain Phase-Amplitude Measurements Between Radiometers to Estimate $T(x)$ Through Inversion ⁽¹⁾**
- **Phase Measurements Between Elements Provide Ability to Reconstruct Scene, Not a Function of Physical Aperture, But of Synthetic Aperture Baseline**
- **Multiple Scene Sampling Can be Used to Provide Sampling of Phase for Higher Resolution Aperture Reconstruction**

¹C.T. Swift et. al., "Initial Results in the Development of a Synthetic Aperture Radiometer", *IEEE Trans. Geosci. Remote Sensing*, vol. 28, pp 614-619, 1990

Sample Theory

- Correlator Output Can be Spatially Sampled and Reconstructed Through Fourier Transform of Samples, i.e

$$V(d_i) = \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \underbrace{P(\theta)}_{\text{Antenna Pattern}} \underbrace{T(\theta)}_{\text{Scene Temperature}} e^{-i2\pi \frac{d_i}{\lambda} \sin(\theta)} d\theta \quad (\text{linear array example})$$

$$\approx \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} P(\theta) T(\theta) e^{-i2\pi \frac{d_i}{\lambda} \theta} d\theta$$

- The Fourier Transform Yields (where D is the Aperture Baseline)

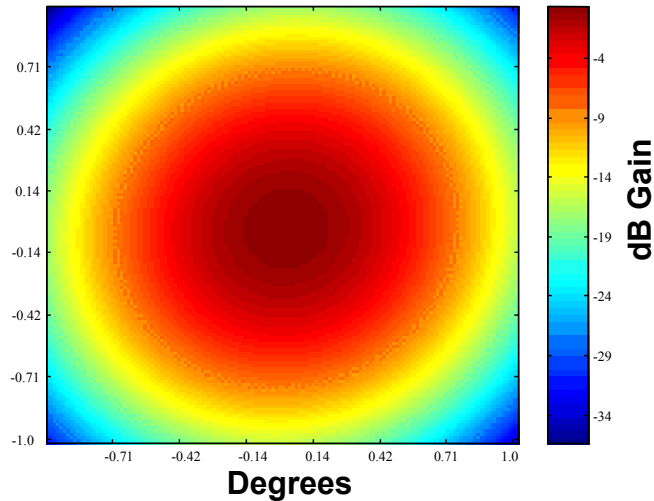
$$F\{V(d_i)\} = \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} P(\theta) T(\theta) \sum_{n=0}^{N-1} e^{i2\pi \frac{k}{N} n} e^{-i2\pi \frac{d_n}{\lambda} \theta} d\theta \text{ for } k = 0, 1, \dots$$

$$= P\left(\frac{k\lambda}{D}\right) T\left(\frac{k\lambda}{D}\right) \text{ for } k = 0, 1, \dots$$

- ↓ *Image Can Be Reconstructed Through the Fourier Transform of the Output Samples*

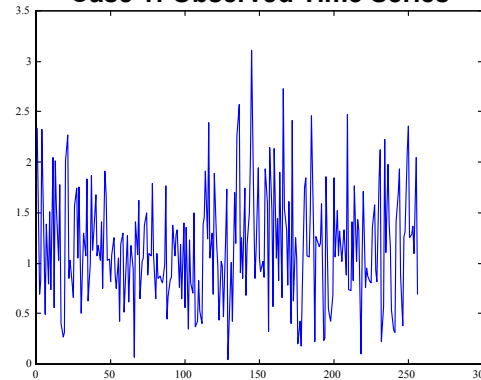
Ideal Point Source Example

Antenna Pattern

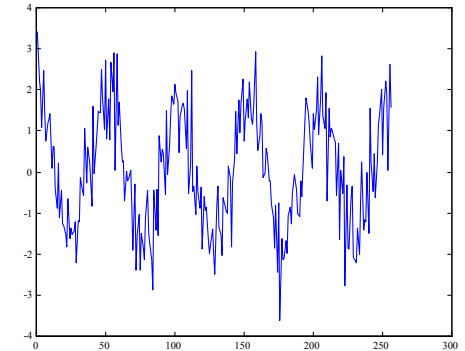


- **Case1: Point Source Located at -0.2865, 0 degrees**
- **Case2: Case1 + point source at 0.2865, 0 degrees**
- **256 Point FFT (for reconstruction)**

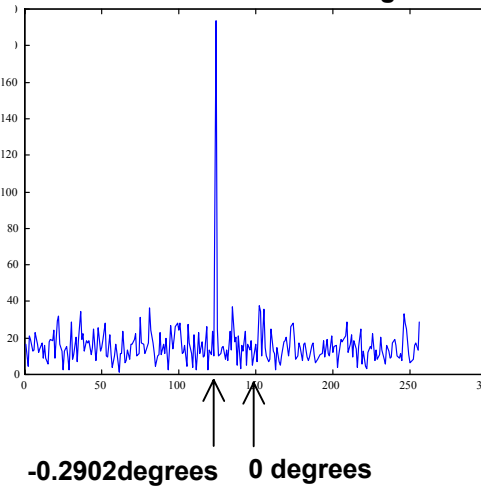
Case 1: Observed Time Series



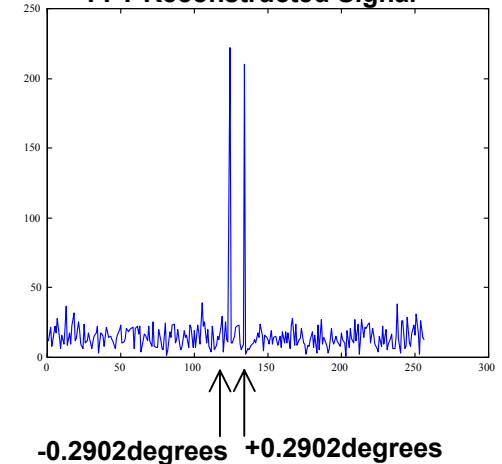
Case 2: Observed Time Series



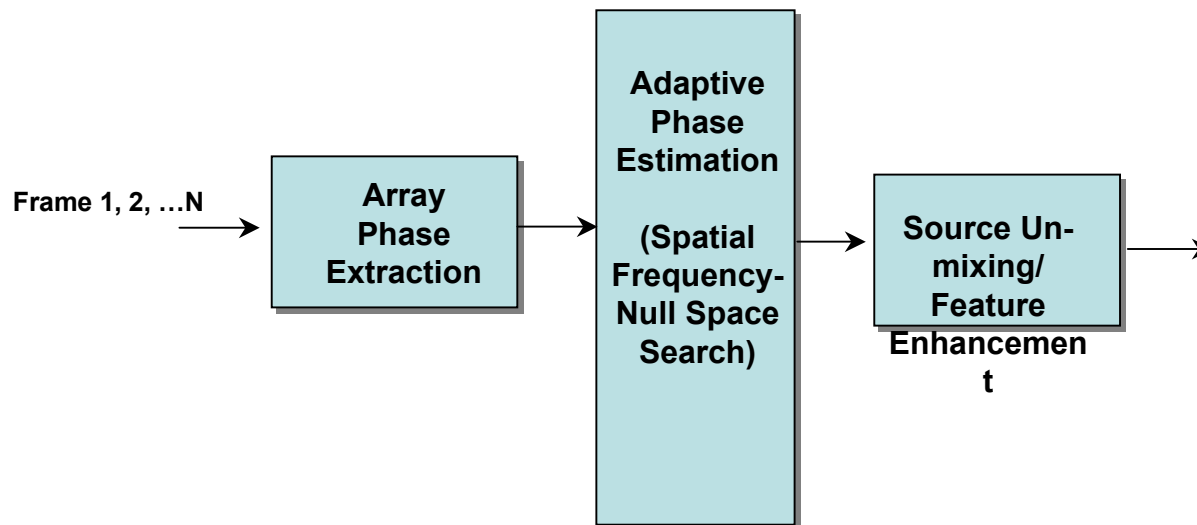
**Case 1:
FFT Reconstructed Signal**



**Case 2:
FFT Reconstructed Signal**

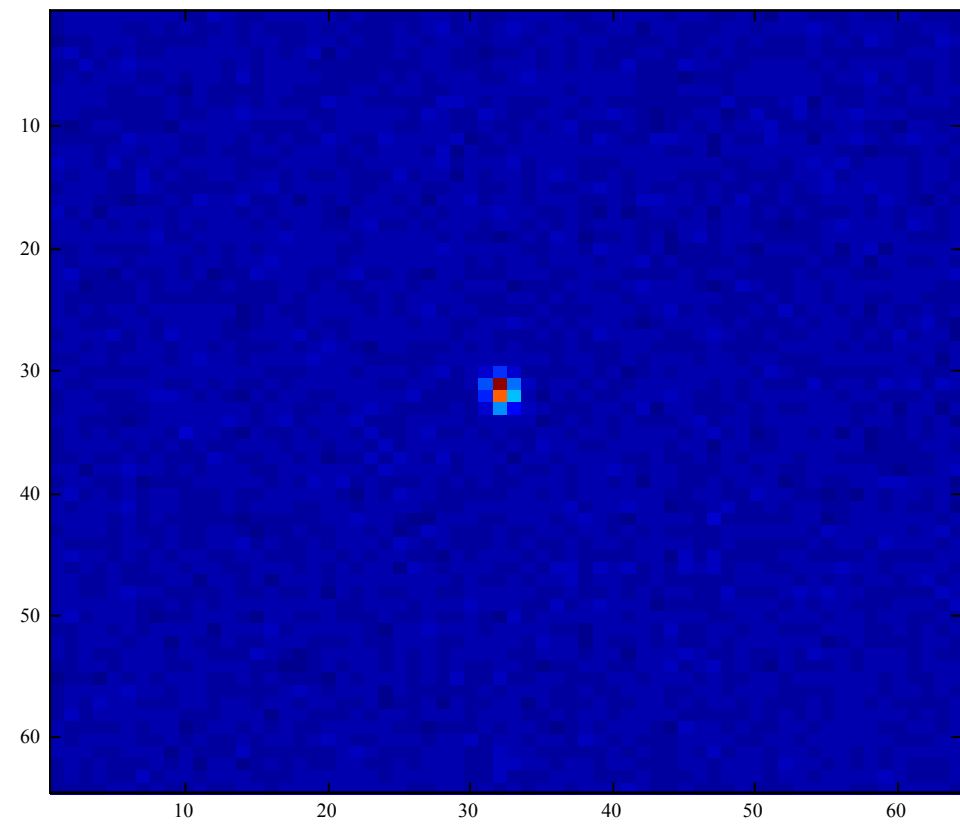


Adaptive Optical Array Processing



Measuring Phase Enables Non-Linear Techniques for Novel Imaging

Input Image Example - Overlapping Psf's (0.2 Pixel Displacement)



Non-linear Processing (Matrix Processor)

$$A(\theta)s(t) + n(t)$$

Vector Space Describing Source Spatial Phase

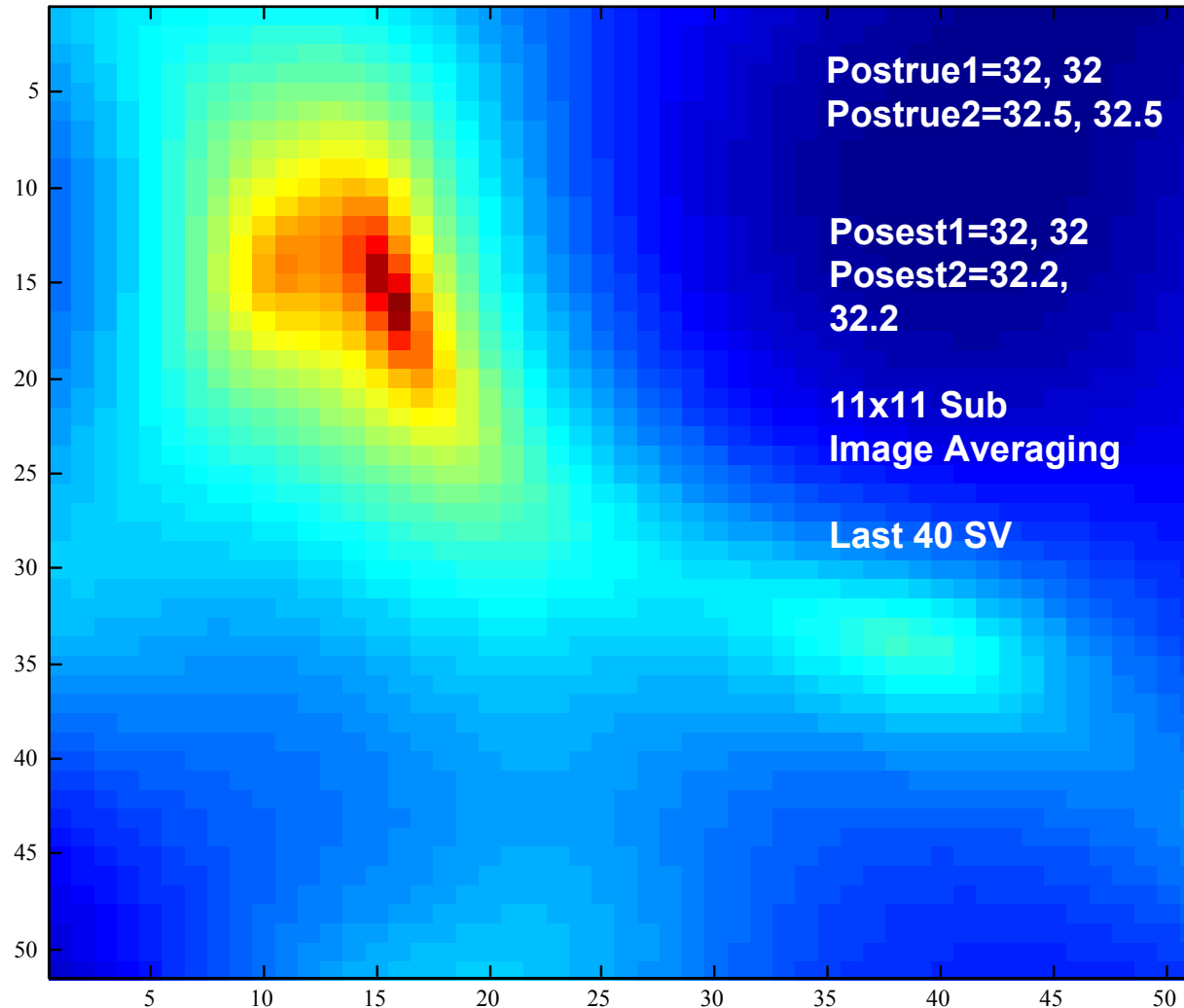
$$W = R^{-1} s(\theta)$$

Feature Enhancement, R = Covariance Matrix

Eigenvectors = Represent Source

Fast Matrix Techniques Provide Joint Optimization
Of Beamforming, and Image Feature and Enhancement

Frequency Domain Music Spectrum
Two Objects 0.5 pixels displaced (5x Spatial Resolution)
Single Frame, Single Band



Optical PBG Materials For Phase Delay Control

There are many examples of effective phase control materials within the PBG scientific literature. An interesting example is published in Applied Physics Letters, Vol. 82, No 15, 14 April 2003 (Ye, Jeong, Mayer and Zhang), “Finite-size effect on highly dispersive photonic-crystal optical components”.

In the second paragraph, page 2380, the authors give the relation

$$\beta = 2\pi (\Delta/\lambda) \eta_{\text{eff}}$$

where β is the phase delay, Δ is the thickness of the material λ is the wavelength and η_{eff} is the effective index of refraction.

For a given Δ and λ , the phase delay, β , depends on the effective index of refraction, η_{eff} . The effective index is given by

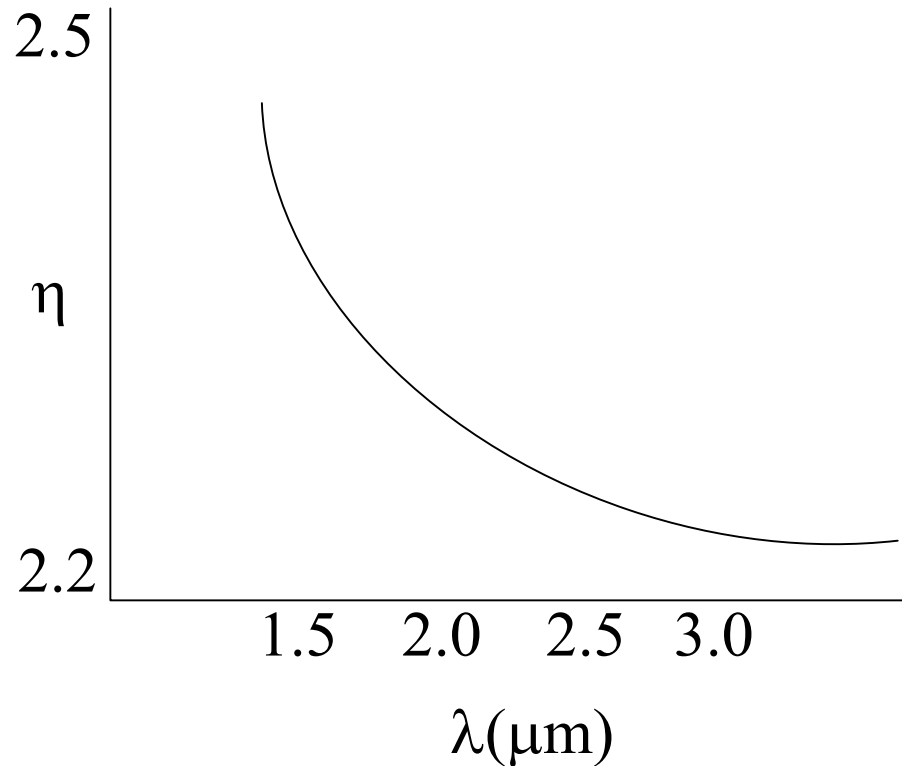
$$\eta_{\text{eff}}^2 = \mu_{\text{eff}} \epsilon_{\text{eff}}$$

This relation suggests that to control the phase delay we must control either μ_{eff} or ϵ_{eff} by the use of some external mechanism.

This external control mechanism should be addressable to the dimension of scale required for the resolution of the application.

self phase adjustment through
the steep dispersion curve (strong dependence of β on η).

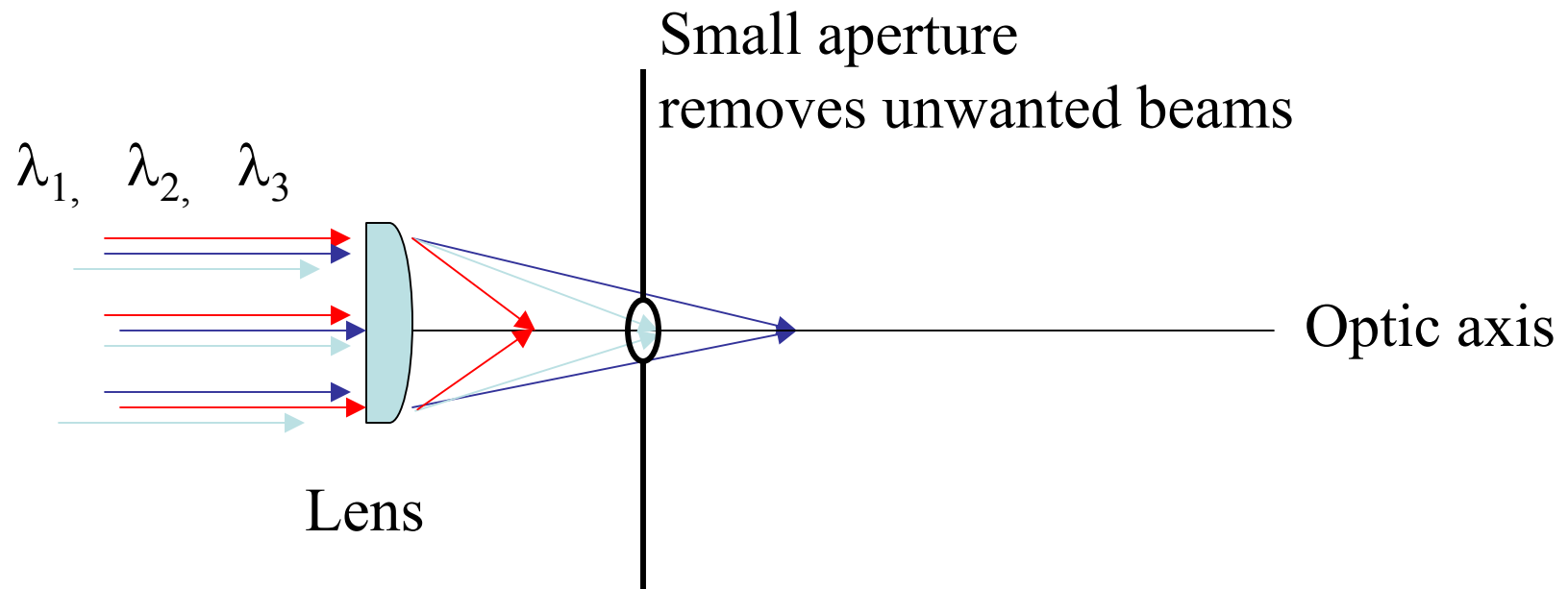
In fig. 2 on page 2381, the authors illustrate that the effective index depends strongly on the wavelength between 1.5 μm and 3.0 μm .



This effect should be adjustable in the optical region as well.

Because of the η dispersion curve relation to phase, we should have a self adjusting delay for each wavelength.

Another way to look at this effect is to consider how it would impact a lens made from this PBG material.



If three distinct wavelengths are sent through the lens they will each have a different focal point.